

Cylinder Deactivation with Mechanically Fully Variable Valve Train

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ABSTRACT

The targets for future gasoline engines in terms of fuel consumption and exhaust gas emissions require the introduction of advanced technologies to increase engine efficiency.

The mechanically fully-variable valve train system UniValve is an effective device to reduce fuel consumption through throttle-free load control. This is achieved by the simultaneous variation of valve lift and valve opening event. The method of cylinder deactivation by closing the gas exchange valves is a further approach to increase the efficiency of combustion engines especially at part load.

This paper presents the combination of both techniques on a downsized, turbo charged 4-cylinder DI gasoline engine. The mechanical integration of the valve shut-off capability for cylinder deactivation into the UniValve system is explained and strategies for the transition between 2-cylinder and 4-cylinder modus are discussed. The thermodynamic benefits through adoption of both technologies are analyzed and a reasonable application area of cylinder deactivation in the engine operation map is pointed out. In the conclusion, the achievable fuel consumption benefits will be presented.

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INTRODUCTION

To focus the further development of gasoline engines on lower fuel consumption and CO₂-emissions, new technologies for worldwide mass production are required. That is why naturally aspirated engines with large displacement are being progressively substituted by supercharged engines that have both less cylinders and a smaller displacement (Downsizing). They offer decisive fuel consumption advantages particularly for relevant operation points in driving cycles.

Another approach achieving reductions in fuel consumption is cylinder deactivation. It is here that the fuel supply is cut off in one part of the engine's cylinders. At the same time, the inlet-and outlet valves are kept closed to avoid pumping losses and to keep the exhaust gas after treatment efficiency. At constant engine torque a BMEP shift of the

fired cylinders is provoked and the efficiency of the entire engine is improved.

In 1981 General Motors were the first to introduce cylinder deactivation with valve shut down in mass production. Whilst this technology was initially mainly reserved to large displacement engines, it has been utilized in the recent past for the entire engine segment. Amongst such uses are also hybrid engines where cylinder deactivation is also used during coast down to minimize cylinder pumping losses and hence to enlarge the recuperation level.

The fully variable valve train offers further efficiency improving measures. Altering the valve stroke as well as valve-opening and closing time allows for advanced load control strategies. In this way pumping losses of the engine can be decisively reduced. The potentials of such fully variable valve trains have been published variously [1], [2], [3], [4]. With Valvetronic, BMW were the first to introduce a fully variable valve train in mass production in 2001. Indeed,

many other car manufacturers have themselves since followed suit.

For the study presented subsequently, the mechanically fully variable valve train system UniValve was chosen. UniValve is able to combine the advantages of cylinder deactivation and dethrottled load reduction, as it has the ability for strong reduction of valve timing towards low lifts, to create zero valve lift and thereby offers the possibility to integrate valve shut off. Beyond this it is possible to include valve lift phasing to increase the residual gas capability of the engine with additional fuel consumption benefits. For system control only low holding and adjusting torques are required. Thus, the thermodynamical potential is not wasted by parasitic losses.

DISCUSSION

CYLINDER HEAD CONCEPT

The research results discussed in this paper are based on a 1.6l SI engine equipped with gasoline direct injection and turbo charging. The engine has a cylinder head with two overhead camshafts and 16 valves that are operated through roller finger followers. The engine is equipped with an inlet cam phaser.

To accommodate the UniValve-system, the engine's cylinder head is modified on the inlet- and outlet side.

A carrier is used here that is fitted on the cylinder head and replaces the conventional valve train with a fully variable valve train on the inlet- and outlet side. Additionally to the inlet side, the outlet side is also equipped with a continuously variable cam phasing system. Both are vane-type, oil driven actuators controlled by solenoid valves (Figure 1).

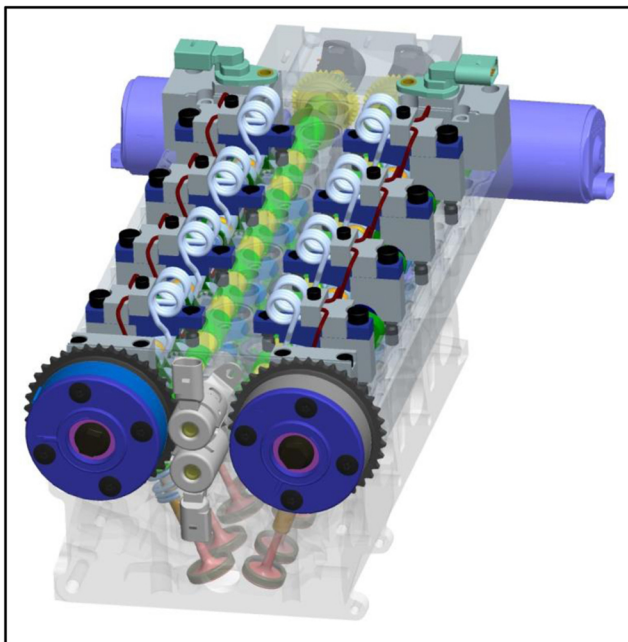


Figure 1. Cylinder head with CVVL valve train and cam phasing on the inlet and exhaust sides

A UniValve system on the inlet side allows for a continuous variation of valve stroke as well as valve timing of all inlet valves. Together with phase adjustment on the inlet side the opening and closing times of the inlet valves can be freely chosen from a broad range what is essential for throttle-free load control. Furthermore, this system accommodates the valve cut-off at cylinders 2 and 3.

The UniValve system on the outlet side is designed accordingly. Here the continuous variation of valve timing combined with cam phasing allows improving fuel efficiency at low loads through extending outlet valve timing offering a potential of 3-4%. Additionally, at high loads short outlet valve timing can be realized to maintain the separation of firing order which is essential for high torques. This application of a fully variable valve train actually requires a separate layout allowing valve timings of 110°-140° cam angle at valve lifts between 7 mm and 9 mm [5]. According to the inlet side, UniValve here also allows valve closure on cylinders 2&3.

Two actuators that are mirrored mounted to the backside of the cylinder head control the valve lifts by operating the control shafts via a worm gear. Thanks to the system's compact design the base engine's package constraints are met.

UNIVALVE-SYSTEM

The UniValve-system is a mechanically fully variable valve train system based on a plane cam mechanism. Its mechanics are based upon a conventional roller finger follower valve train.

This system gains its variability through an additional intermediate rocker arm that is introduced between the camshaft and the roller finger follower. This rocker arm features a working lobe, being in contact to the finger follower's roller.

Beyond that, the contact to camshaft, circular guide and control shaft is sustained by rollers with needle roller bearings. To secure the contact between all components at all times, additional return springs are introduced. (Figure 2)

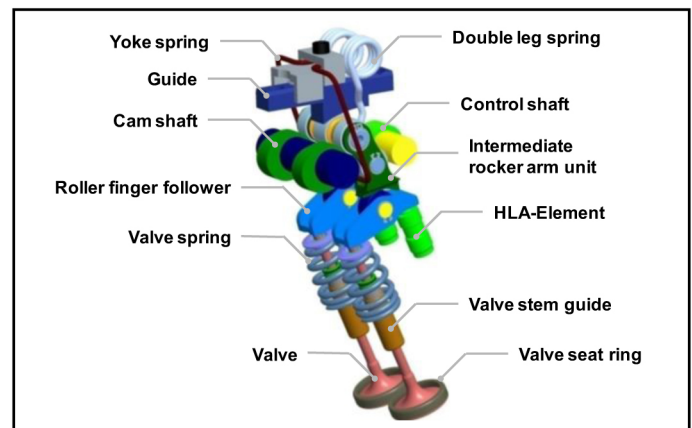


Figure 2. Design of the UniValve CVVL-System

The double leg spring maintains the contact between intermediate rocker arm and camshaft whilst the yoke spring lets the rocker arm follow the control shaft.

The intermediate rocker arms of two valves are combined into one single rocker arm unit with a common guide roller. This effectively reduces the amount of components and therefore also the system inertia. A further advantage is that each valve pair merely requires one double leg spring and one yoke spring. (Figure 3)

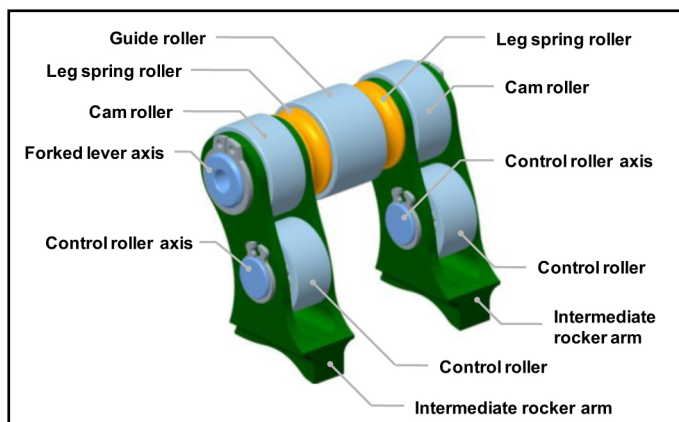


Figure 3. Intermediate rocker arm unit

The adjustment of the desired valve lift is achieved by turning the control shaft which in the simplest case is an eccentric shaft with a circular shape. Through rotating this shaft the area of the working curve engaged effectively is changed. Thus, different valve peak lifts occur combined with different valve events. Figure 4 discloses the function of the system at different positions of the control shaft. In each case the camshaft is shown in the position with the maximum deflection of the intermediate rocker arm.

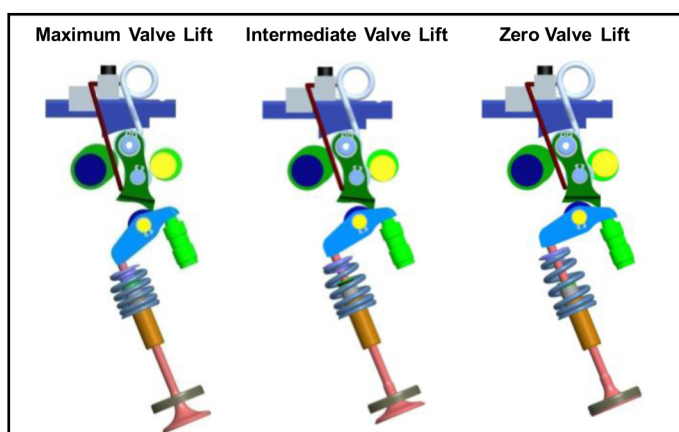


Figure 4. Variation of valve lift through rotation of the control shaft

The complete travel from maximum down to zero peak lift only requires half a rotation of the control shaft. During this process, the roller of the intermediate rocker arm visits either the top or the lower surface of the control shaft lobe, depending on the direction of rotation.

The resulting characteristic of valve lift vs. valve timing strongly depends on the designed UniValve geometry and kinematic layout. Figure 5 shows this relation measured on the prototype cylinder head which was described before during rotation of the control shaft from maximum to zero valve lift.

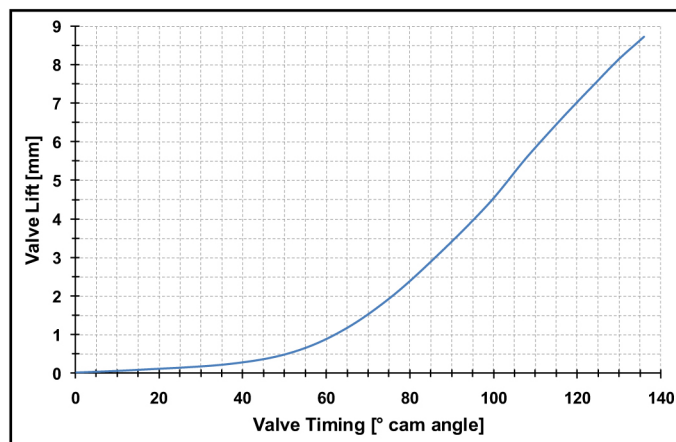


Figure 5. Valve lift vs. valve timing measured on prototype cylinder head

UNIVALVE AND CYLINDER DEACTIVATION

Since only one side of the control shaft is being used for a fully variable adjustment of the valve lift/valve timing, there is the possibility to design alternative characteristics for the adjustment on the second side.

This is realized through an adequate design of the control shaft profiles. The shaft is thus either pivoted clockwise or anti-clockwise, depending on which characteristic is going to be applied. This technique can also be used to deactivate the cylinders.

Figure 6 contrasts two possible profiles protected for cylinder deactivation. The lower sides of both profiles are identical and allow the parallel variance of all intake valves from maximum peak lift down to zero valve lift. On their upper side the first profile reverses this event. The second profile is modified to stay at zero peak lift for a wider area.